INSTRUCTION MANUAL

PLATINUM RESISTANCE TEMPERATURE STANDARDS

SERIES 162

Rosemount

SERIES 162
PLATINUM RESISTANCE TEMPERATURE STANDARDS
MODELS 162CE, 162D, 162K, 162N

CAUTION
READ BEFORE ATTEMPTING
INSTALLATION OR OPERATION
TO AVOID POSSIBLE
WARRANTY INVALIDATION

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SECTION I
INTRODUCTION

GENERAL

The Rosemount Series 162 Platinum Resistance Temperature Standards are precision laboratory thermometers which convert temperature, as defined by the International Practical Temperature Scale (IPTS), to resistance. Four models are included in the series: the Model 162CE interpolates temperatures over a −200 to +650°C range; the Model 162D operates over a range of −260 to +250°C; the Model 162K, with a range of 0 to +1100°C, converts temperature to resistance up to the melting point of gold; and the Model 162N interpolates temperatures from −200 to +400°C. All four models have a platinum resistance sensing element made from high purity platinum wire, wound essentially strain-free, and then fully annealed. The leadwires connecting the sensing element to the housing assembly are insulated, and the element is hermetically sealed.

APPLICATION

The Series 162 Thermometers can be classified as primary or secondary standards. A primary standard is defined as one or more calibrated standards used to transfer the IPTS from a standardizing laboratory to a customer's own laboratory. Primary standards are used to calibrate secondary or working standards, which in turn are used for routine calibration of other temperature-sensitive devices.

Classification and use of the resistance thermometers depends on accuracy requirements. A single thermometer may be used for all purposes, or two or more thermometers may be used so that there is always a spare in the event one thermometer malfunctions.

Typically, Models 162CE, 162D, and 162K are used as primary standards, and Model 162N as a secondary standard.

CALIBRATION

In order to function as a temperature standard, each 162 Thermometer must have a calibration traceable to a recognized national standards laboratory. Models 162CE and 162D can be submitted to the National Bureau of Standards (NBS) for calibration. Rosemount supplies calibration results traceable to the NBS and resistance or resistance ratio versus temperature tables for all four thermometer models discussed in this manual. Calibration schedules are described in Section V.

SECTION II
SPECIFICATIONS

GENERAL SPECIFICATIONS

DIMENSIONS: See Figures 1, 2, 3, and 4.

WEIGHT:

162CE: 10.7 ounces (305 gm)
162D: 0.4 ounces (10 gm)
162K: 10.0 ounces (285 gm)
162N: 8.3 ounces (235 gm)

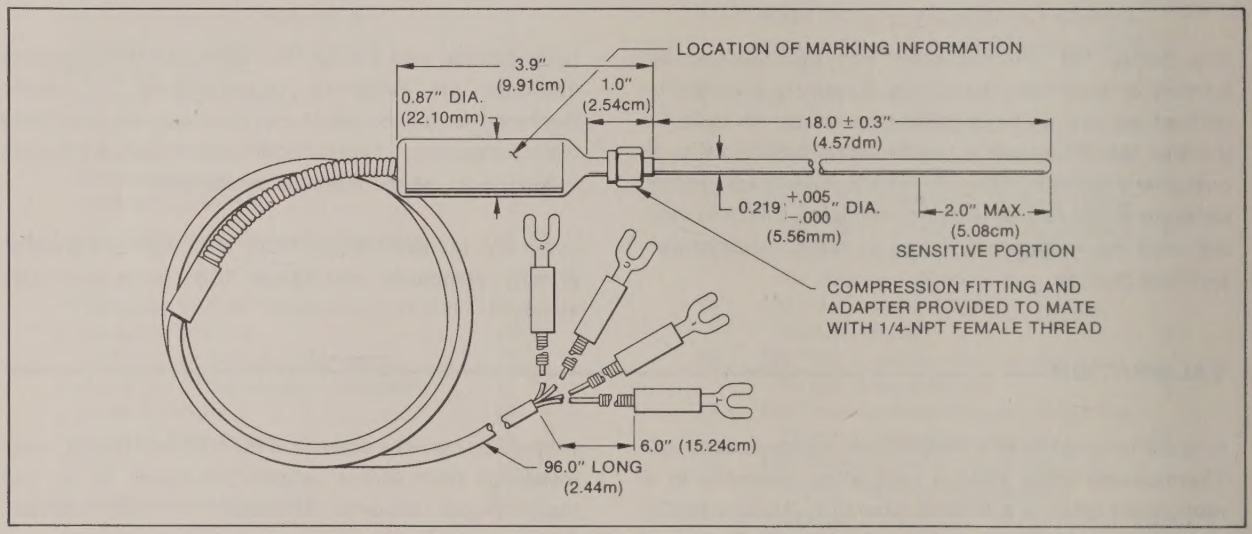

Figure 1. Model 162CE Temperature Standard - Dimensions.

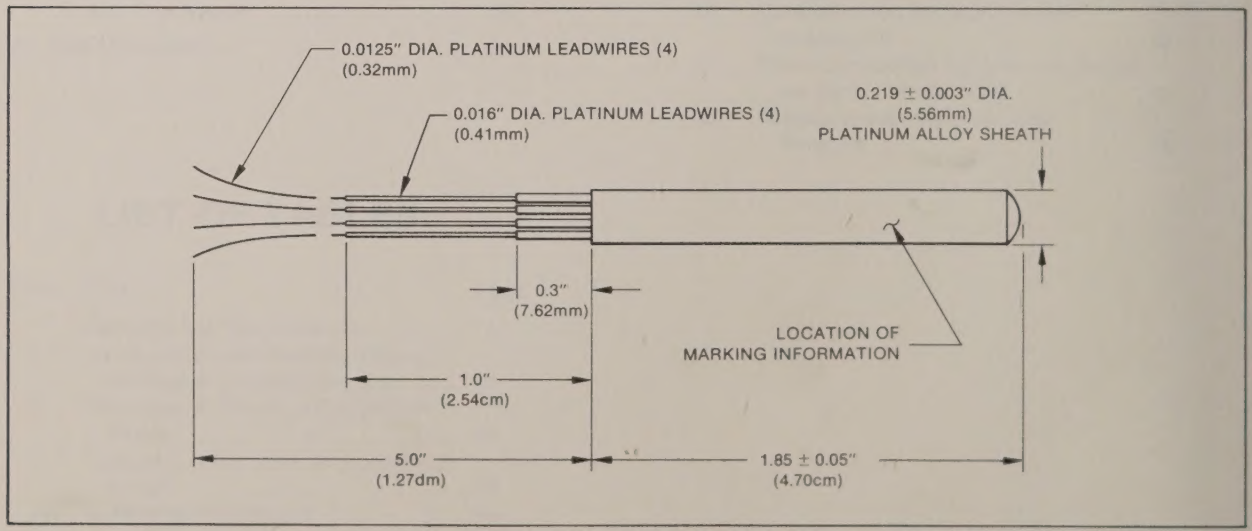

Figure 2. Model 162D Temperature Standard - Dimensions.

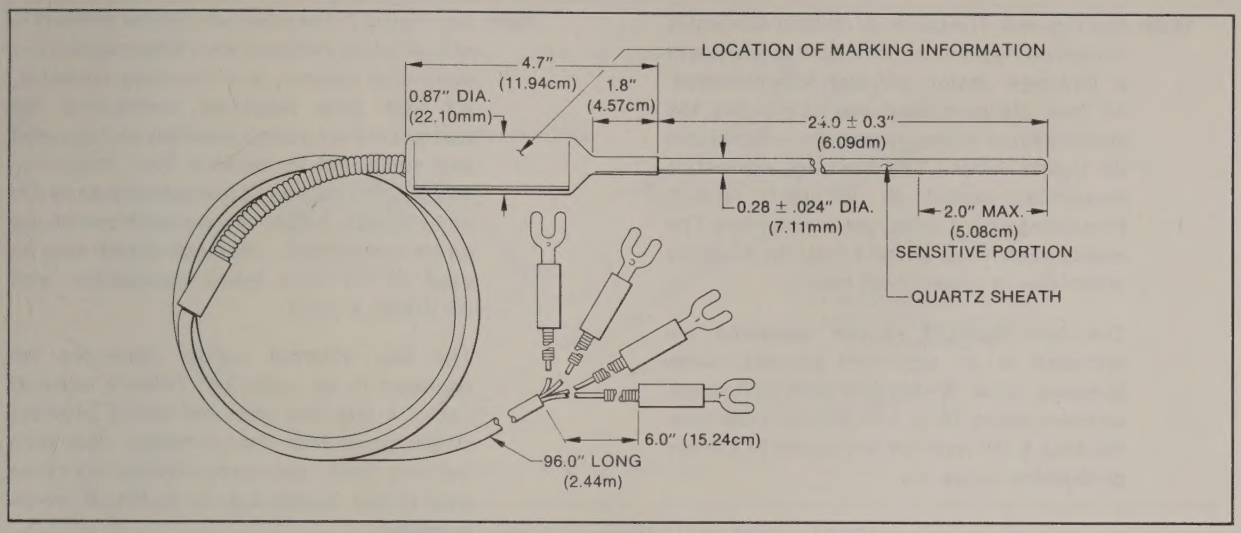

Figure 3. Model 162K Temperature Standard - Dimensions.

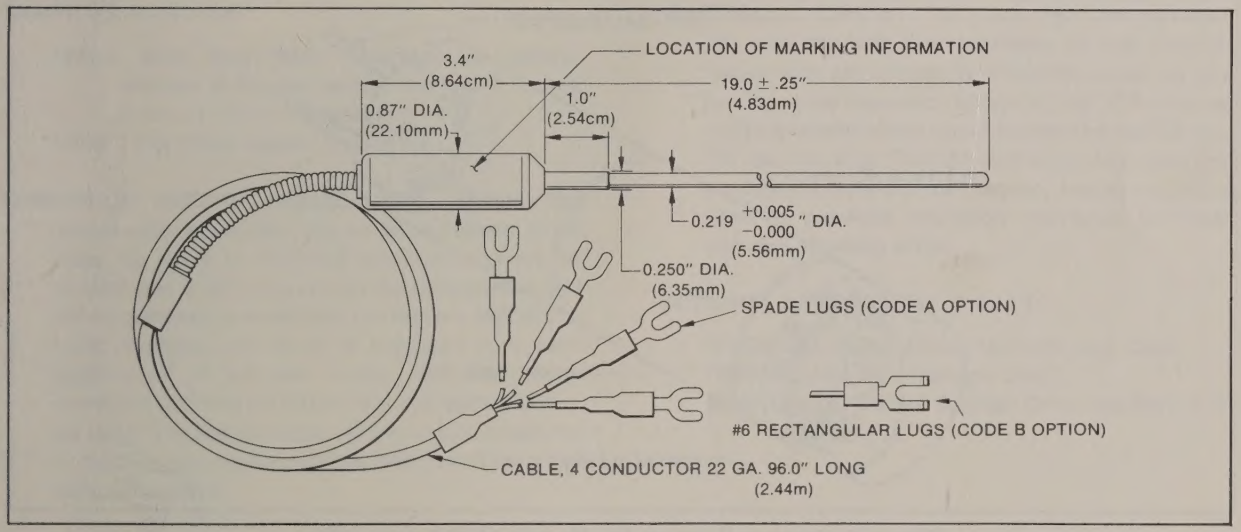

Figure 4. Model 162N Temperature Standard - Dimensions.

CONSTRUCTION:

162CE: See Figure 5. The platinum resistor element is of high purity platinum wire, wound strain-free, and then fully annealed. All four platinum leadwires connecting the element to the housing assembly are insulated by ceramic tubes. The sensing element is hermetically-sealed in an INCONEL X-750® metal sheath containing a helium-oxygen atmosphere. The metal sheath may be used in all fluid media compatible with 316 stainless steel or INCONEL X-750®. A compression fitting and mating adapter enable the 162CE to be used in pressure vessels up to 2000 psia.

The four external copper leadwires are enclosed in an eight-foot silicone rubber jacketed cable. A stainless steel coil spring provides strain relief into the stainless steel housing. Each leadwire terminates in a heavy gold-plated spade lug.

162D: See Figure 5. The platinum resistor element is of high purity platinum wire, wound strain-free, and then fully annealed. All four platinum leadwires connecting the element to the housing assembly are insulated by ceramic tubes. The sensing element is hermetically-sealed in a platinum alloy sheath containing a helium atmosphere. The platinum alloy sheath may be used in all nonconductive fluid media compatible with platinum, gold, and glass. A uniform external diameter enables the 162D to be easily installed in copper blocks, cryostats, and other calibration fixtures.

162K: See Figure 6. The platinum resistor element is of high purity platinum wire, held strain-free in a "birdcage" design, and then fully annealed. All four platinum leadwires connecting the element to the housing assembly are insulated by quartz tubes. The sensing element is hermetically-sealed in a quartz sheath containing an argon-oxygen atmosphere. The quartz sheath has a matte finish to minimize errors due to radiant heat loss.

The four external copper leadwires are enclosed in an eight-foot silicone rubber jacketed cable. A stainless steel coil spring provides strain relief into the stainless steel housing. Each leadwire terminates in a heavy gold-plated spade lug.

162N: See Figure 7. The platinum resistor element is of high purity platinum wire, bifilar wound in a strain-free manner, and then fully annealed. All four gold leadwires connecting the element to the housing assembly are insulated and supported by ceramic fiber insulation. The sensing element is hermetically-sealed in an INCONEL X-750® metal sheath containing an air atmosphere. The metal sheath may be used in all fluid media compatible with INCONEL X-750®.

The four external copper leadwires are enclosed in an eight-foot Teflon® jacketed cable. A stainless steel coil spring provides strain relief into the anodized aluminum housing. Each leadwire terminates in a heavy gold-plated spade lug or a No. 6 screw terminal.

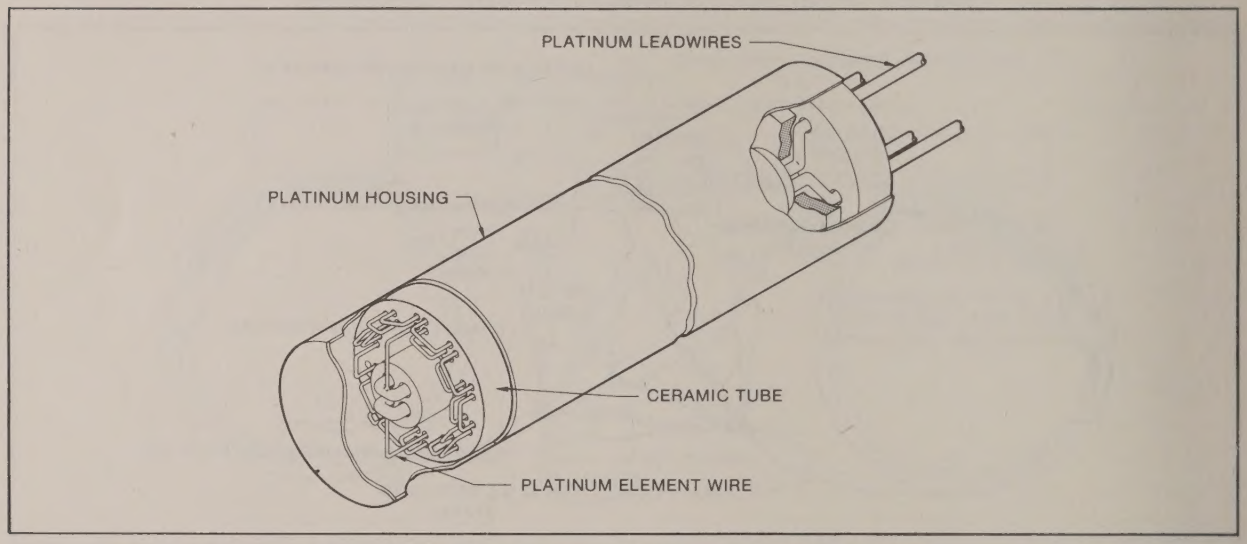

Figure 5. Sensing Element for Models 162CE and 162D.

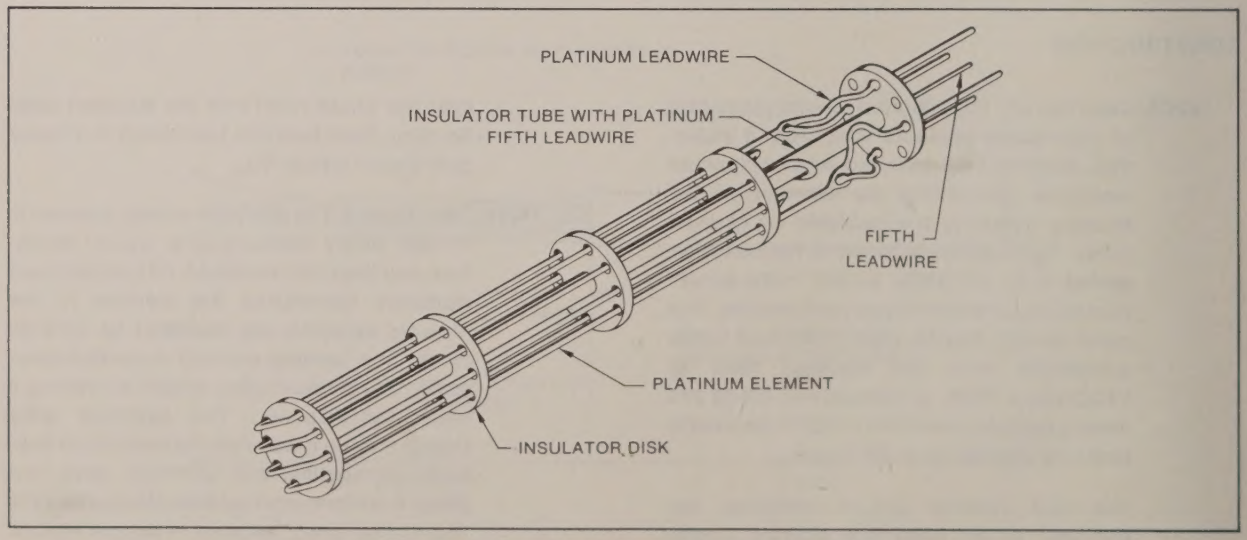

Figure 6. Sensing Element for Model 162K.

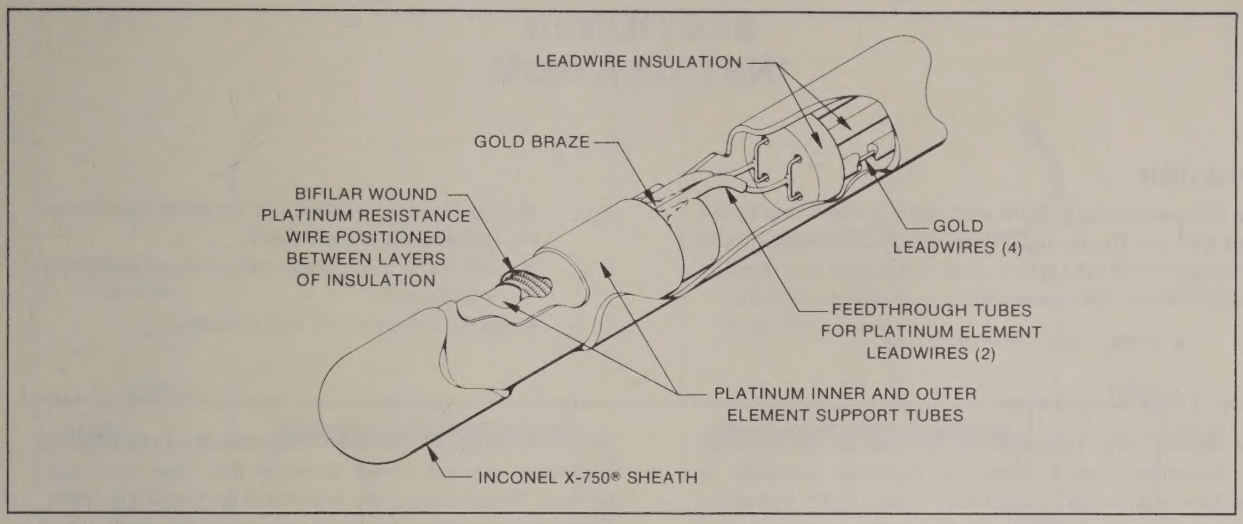
LEADWIRE INSULATION
GOLD BRAZE
BIFILAR WOUND PLATINUM RESISTANCE WIRE POSITIONED BETWEEN LAYERS OF INSULATION
GOLD LEADWIRES (4)
FEEDTHROUGH TUBES FOR PLATINUM ELEMENT LEADWIRES (2)
PLATINUM INNER AND OUTER ELEMENT SUPPORT TUBES
INCONEL X-750® SHEATH

Figure 7. Sensing Element for Model 162N.

SENSITIVE PORTION:

162CE, 162K, and 162N: The platinum resistor element is located within the first 2 inches (5.08cm) of the sheath tip.

162D: The entire sheath is sensitive.

IMMERSION DEPTH (162CE, 162K, 162N): The temperature standards should be immersed to an adequate depth to minimize conduction errors. In general, the depth depends on the temperature and the medium being measured. For Models 162CE and 162N, 4 inches (10.16cm) is sufficient in a well-agitated oil or ice bath. Model 162K should be immersed 6 inches (15.24cm) in a well-agitated oil or ice bath; this thermometer also is long enough for accurate measurements in well-designed fixed point cells or furnaces.

ELECTRICAL CIRCUIT: All Series 162 Thermometers are provided with four leadwires so that leadwire resistances are effectively cancelled when using a four-terminal resistance bridge. Model 162K also has a fifth leadwire which runs between the resistor and the rear housing. The fifth leadwire is insulated and equidistant from the four resistor leadwires, and is used to measure insulation resistance to detect possible shunting errors.

OPTIONAL STORAGE EQUIPMENT:

162CE and 162N: Model 162H Storage Case.

162D: Model 162L Storage Case.

162K: Model 162MI Storage Case (supplied with 162K).

TABLE 1

PERFORMANCE SPECIFICATIONS

Specification	Model 162CE	Model 162D	Model 162K	Model 162N
Temperature Range	−200 to +650°C	−260 to +250°C	0 to +1100°C	−200 to +400°C
Pressure Range	0 to 2000 psia	0 to 1000 psia	Not Applicable	0 to 1000 psia
Resistance-Temperature Relationship:				
Ice Point Resistance	25.55 ohms	25.55 ohms	0.22 ohms	100 ohms
Resistance Over Temperature Range	4.3 to 85.4 ohms	0.03 to 72.7 ohms	0.22 to 1.05 ohms	16.8 to 250 ohms
Slope	0.1 ohms/°C	0.1 ohms/°C	0.001 ohms/°C	0.39 ohms/°C
Stability[1]	0.010°C/year	0.010°C/year	0.010°C/100 hours	0.10°C/year
Self-Heating	85 mW/°C	85 mW/°C	11 mW/°C	28 mW/°C
Time Constant[2]	3.0 seconds	5.0 seconds	10.0 seconds	1.0 second
Insulation Resistance	>1000 Megohms @ 23°C >75 Megohms @ 650°C	>1000 Megohms @ 23°C >100 Megohms @ 250°C	>1000 Megohms @ 23°C >1 Megohm @ 1100°C	>100 Megohms @ 23°C

[1] The stabilities are typical and for reference only. Actual stability depends on application conditions.

[2] Medium: Water at 77°C flowing at 1 m/second.

SECTION III
INSTALLATION

LOCATION

The calibration equipment and readout instrumentation used with the Series 162 Temperature Standards should be located in a laboratory area conducive to precision measurements. Environmental requirements include:

- Quiet, clean, and draft-free.
- Low building vibration (if sensitive light beam galvanometers are used).
- Low radio frequency, magnetic, or electrical interference.
- Stable temperature and humidity.

HANDLING

The Series 162 Temperature Standards are delicate thermometers which must be handled carefully to maintain calibration accuracy. Low level vibration, shocks, etc. may cause the resistance to increase over a period of time. Proper handling and use will prolong the life of the instruments.

When not in use, the thermometers should be stored in the protective storage cases listed in the "Specifications" section. This is especially important for the Model 162K, which is extremely fragile because of its long quartz sheath.

MOUNTING

Temperature standards are used most frequently for calibrating other temperature-sensitive devices. Typical installations of the thermometers for calibration of temperature sensors are shown in Figures 8, 9, 10, 11, and 12.

Models 162CE and 162N have an INCONEL X–750® metal sheath which is compatible with nearly all common calibration liquids (Figures 8, 9, and 10). The housing (handle) should not be submerged in liquid, and water vapor should not be allowed to condense on or in the housing since it may cause low insulation resistance between thermometer leadwires.

If metal blocks are used to improve bath temperature stability, ensure that a close fit is maintained between the thermometer sheath and the hole in the metal block. A clearance of 0.002 to 0.003 inch (0.05 to 0.08mm) normally is satisfactory to achieve good thermal contact. Since the thermal expansion coefficient of the sheath is less than that of common block materials such as copper, aluminum, or nickel, binding usually is not a problem.

The Model 162CE Temperature Standard is supplied with a compression fitting and a male 1/4-NPT adapter. This enables the 162CE to be used in applications under pressure up to 2000 psia (13.8 M Pa).

The Model 162K Temperature Standard must be mounted very carefully to avoid breaking the fragile quartz sheath (Figure 11). The thermometer is necessarily long to minimize errors due to thermal conduction in a high temperature environment. The area in which the temperature measurement is made must be well insulated and shielded to minimize thermal gradients and radiant heat loss. Clearance between the thermometer sheath and metal block should be adequate to allow easy insertion and prevent breakage. Wipe the sheath clean with a suitable solvent to remove fingerprints when using the thermometer above 400° C.

The Model 162D Temperature Standard can be immersed directly in any nonconductive fluid compatible with the thermometer's materials (Figure 12). When immersed, secure the thermometer to a post or other structure to prevent mechanical shock. Ensure that this support does not introduce an undesirable heat path. Ideally, at least 5 inches (12.7 cm) of the leadwires should be at approximately the same temperature as the thermometer to minimize conduction errors. The leadwires should be secured to a supporting member, yet free to expand and contract.

In addition, a Teflon® sleeve should be slipped over each leadwire of the 162D to prevent shorting to each other or to ground. Note, however, that the sleeves will not hermetically seal the leadwires; thus, any tendency of the fluid to conduct will decrease the insulation resistance between the leadwires, causing an error. Note, too, that even nonconductive fluids may become conductive at temperatures below the ambient dew point because of condensed moisture. Nonconductive fluids also may tend to become conductive at elevated temperatures.

For installations where the fluid is conductive or is not compatible with the thermometer's materials, the 162D can be mounted in a thin wall tube. In this application, a much better thermal contact is made by surrounding the thermometer with a compatible nonconductive liquid rather than air, particularly if the gap between the tube and the thermometer is more than 0.003 inch (0.08 mm).

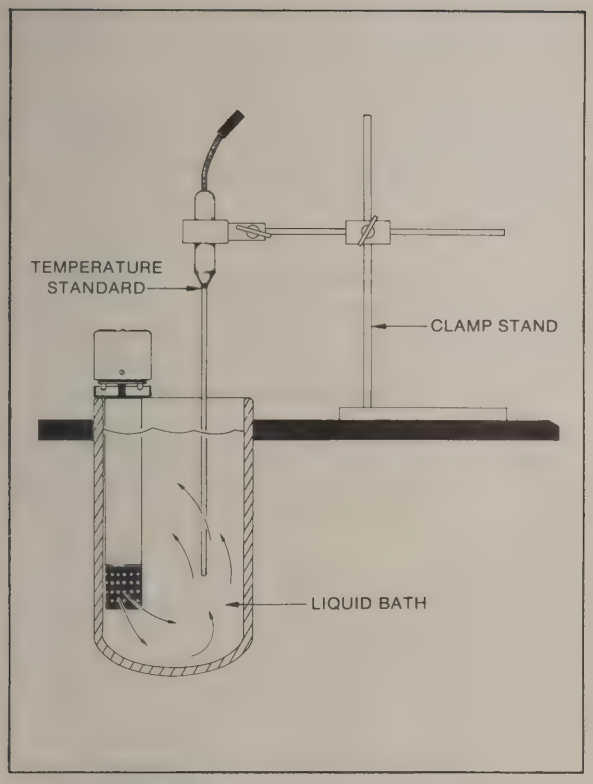

Figure 8. Liquid Bath Installation - Models 162CE, 162N.

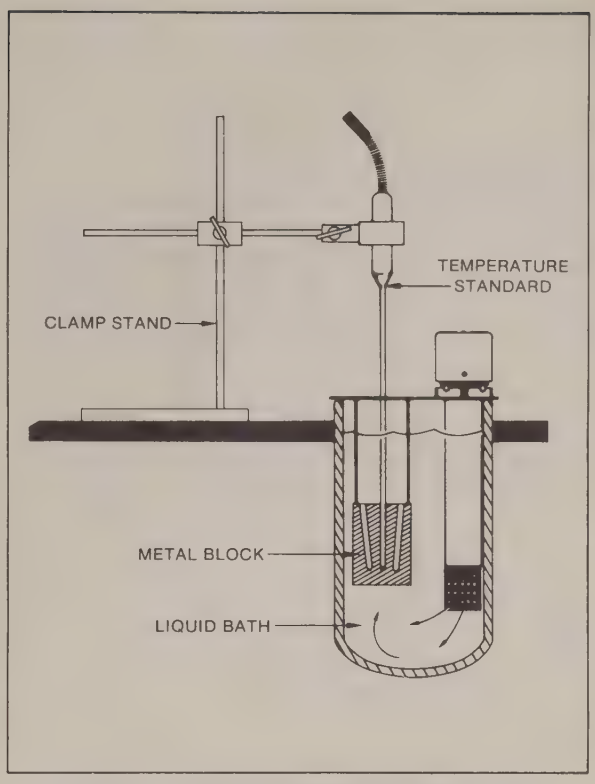

Figure 9. Metal Block Installation in a Top-Stirred Liquid Bath - Models 162CE, 162N.

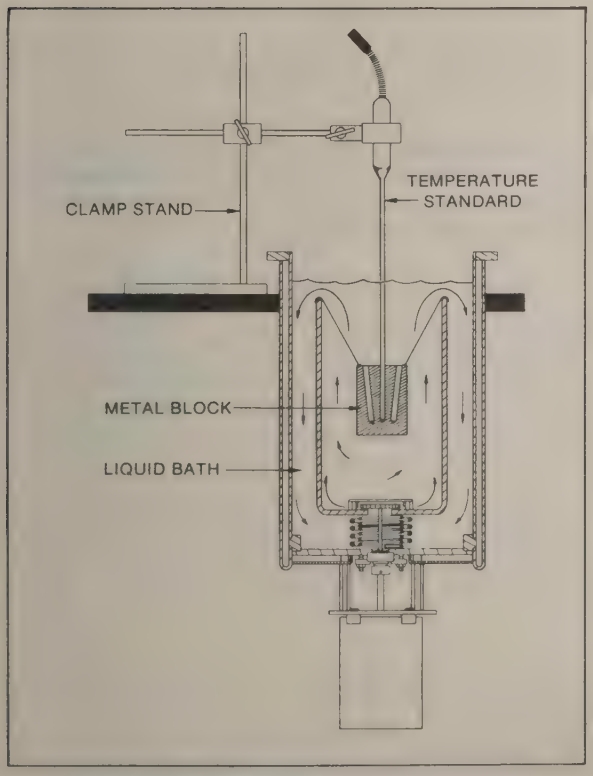

Figure 10. Metal Block Installation in a Bottom-Stirred Liquid Bath - Models 162CE, 162N.

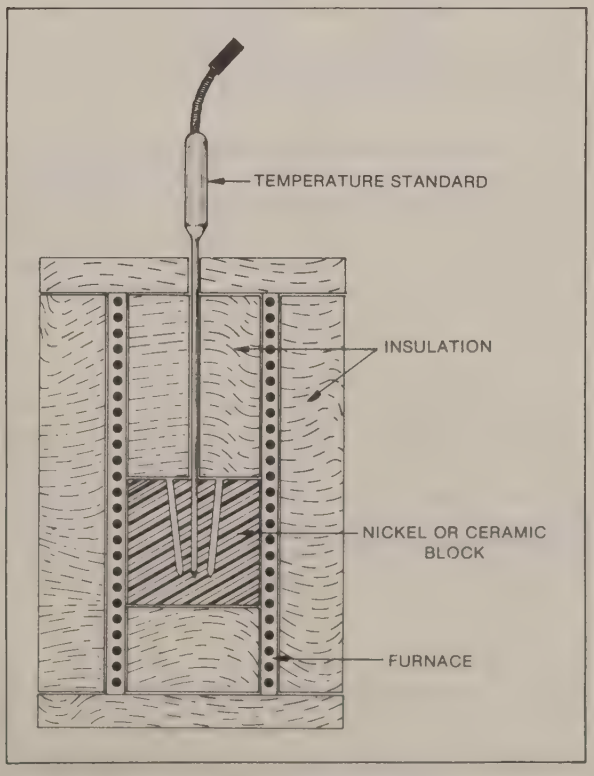

Figure 11. Furnace Installation - Models 162CE, 162K.

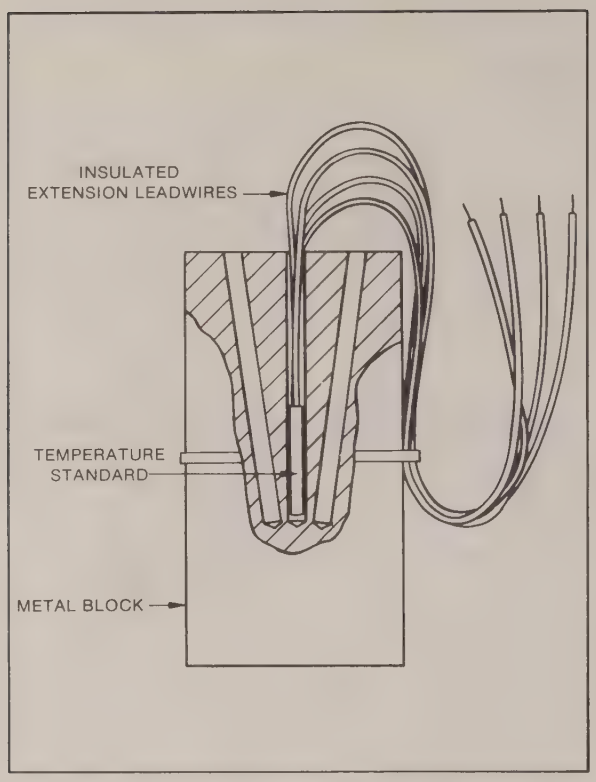

Figure 12. Cryogenic or Special Purpose Metal Block Installation - Model 162D.

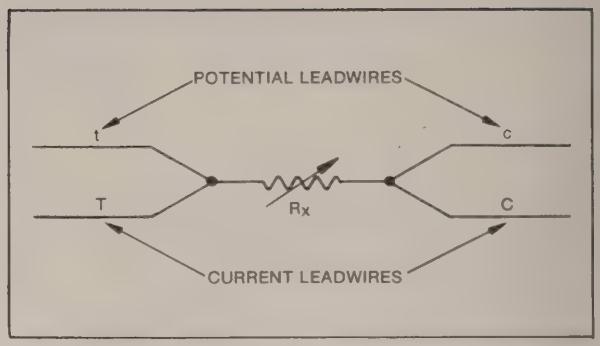

Figure 13. Circuit Schematic for Models 162CE and 162K Temperature Standards.

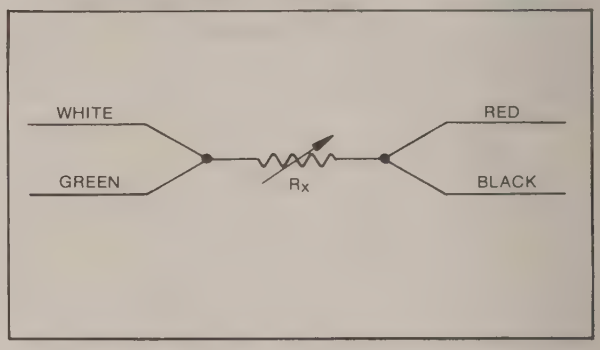

Figure 14. Circuit Schematic for Model 162N Temperature Standard.

LEADWIRE IDENTIFICATION

All of the Series 162 Temperature Standards discussed in this manual have basically the same circuit schematic (shown in Figures 13 and 14) which includes four leadwires for the effective cancellation of leadwire resistance. Although not required, it is recommended that the readout instrument used with any thermometer be equipped to handle four-terminal resistors.

For the 162CE and 162K Temperature Standards, the designations "C" and "T" on the spade lugs refer to the "current" leadwires which normally carry the same current as the sensing element. "C" and "T" leadwire resistances are matched very closely to minimize the bridge unbalance when the leadwires are commutated on certain bridges. The resistances in the "potential" leadwires "c" and "t" are not as critical since these leadwires are in the battery or detector circuit. Because there is no difference in the construction of the "potential" leadwires, under most circumstances it makes no difference which leadwires are used.

The 162D Temperature Standard does not have leadwire identification. It usually is necessary to add extension leadwires to the 162D. Teflon®-insulated copper leadwires, 24 to 26 gauge, normally are satisfactory for low temperature work. The leadwires should be the same length with the same resistance. Use an ohmmeter for leadwire identification on the 162D.

The 162N Temperature Standard has white and green leadwires on one side of the sensing element and red and black leadwires on the other side.

MEASUREMENT INSTRUMENTS

Several types of resistance measuring instruments can be used with the Series 162 Temperature Standards. Typically, resistances are measured with a precision bridge or potentiometer, and a galvanometer or electronic null detector. The accuracy and resolution of this equipment should be from 2 to 5 ppm (0.001% or better) to

be equivalent to the best thermometer calibration of 0.001°C. If the instrument is designed to make four-terminal resistance measurements, make sure it is designed to work with individual leadwire resistances up to approximately 1.5 ohms (162CE and 162K). Refer to the appropriate manufacturer's instructions and Figures 13 and 14 when connecting a temperature standard to a readout instrument.

Figures 15 and 16 illustrate two common methods for making four-terminal bridge resistance measurements, although various other types of instruments also can be used. Consult the instruction manuals for these instruments for proper connection and use.

In some instances it may be necessary to use a two- or three-terminal bridge for measuring resistances. Minimize leadwire resistance effects in those measurements by taking multiple readings. Refer to Figures 17 and 18 for thermometer connections to two- and three-terminal bridges.

Figure 19 illustrates a common method in which the resistance of a thermometer is converted to direct digital readout of temperature. The type of instrument used in this application includes circuitry which compensates for the non-linearity of the resistance-temperature relationship of platinum.

Digital multimeters also may be used with Series 162 Temperature Standards, provided the resolution and accuracy is satisfactory for the application. However, the current which is applied to the temperature standard is generally fixed and may cause a self-heating error, especially for low thermometer resistances.

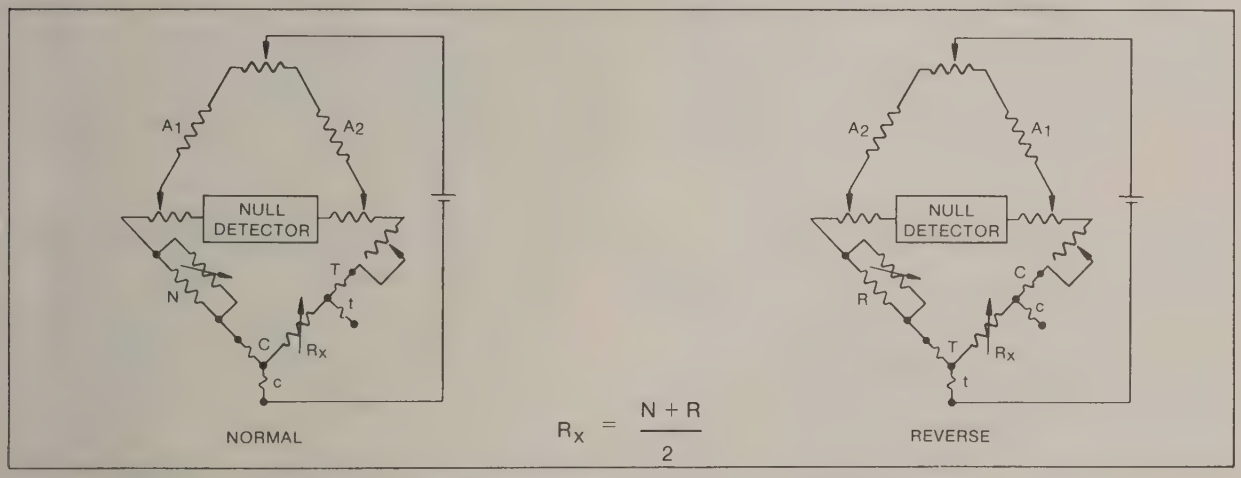

Figure 15. 162 Thermometer Circuit Using a Mueller Bridge.

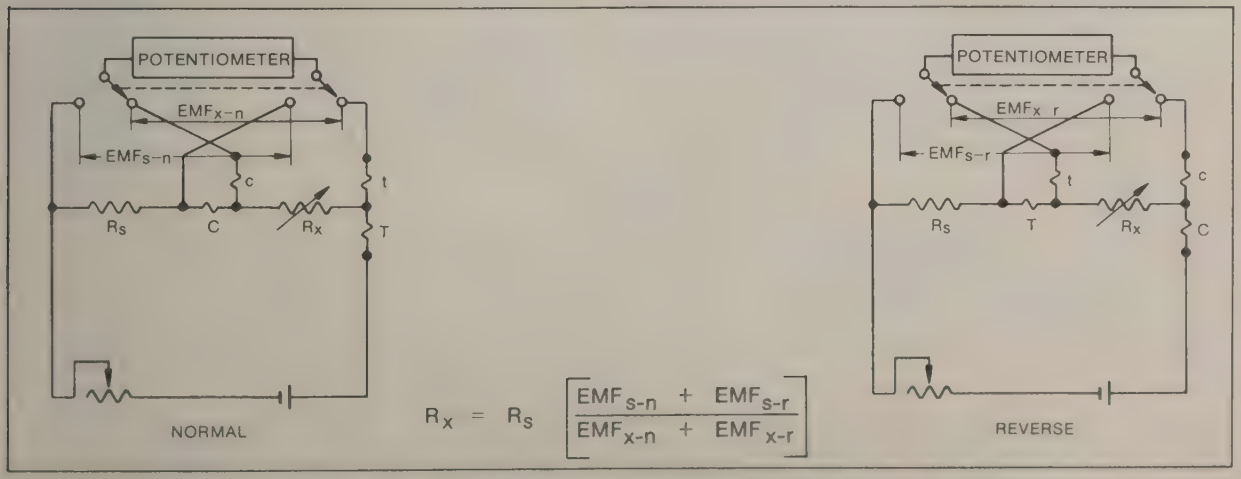

Figure 16. 162 Thermometer Circuit Using a Single Potentiometer.

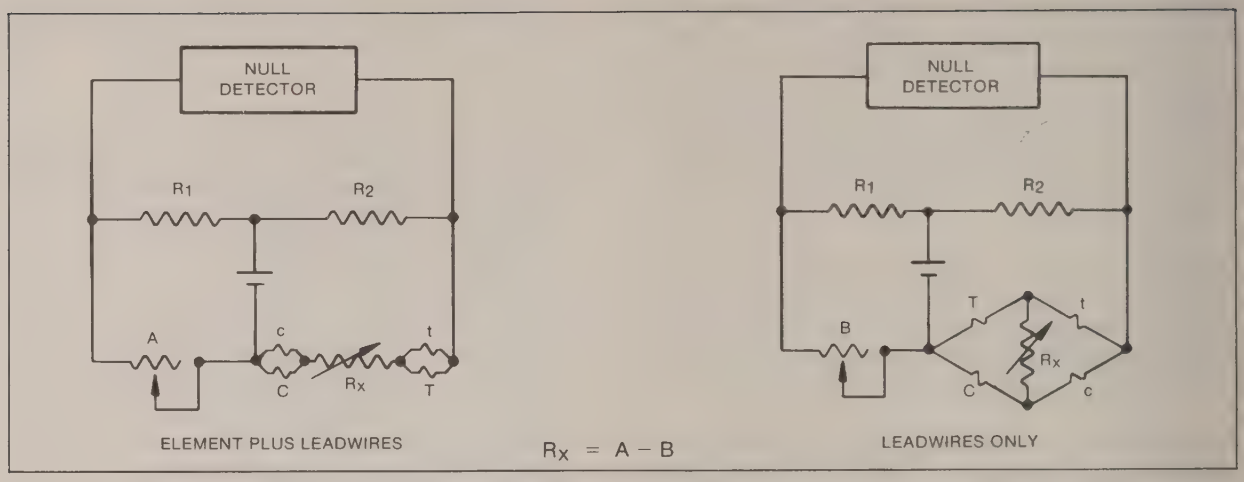

Figure 17. 162 Thermometer Circuit Using a Two-Terminal Wheatstone Bridge.

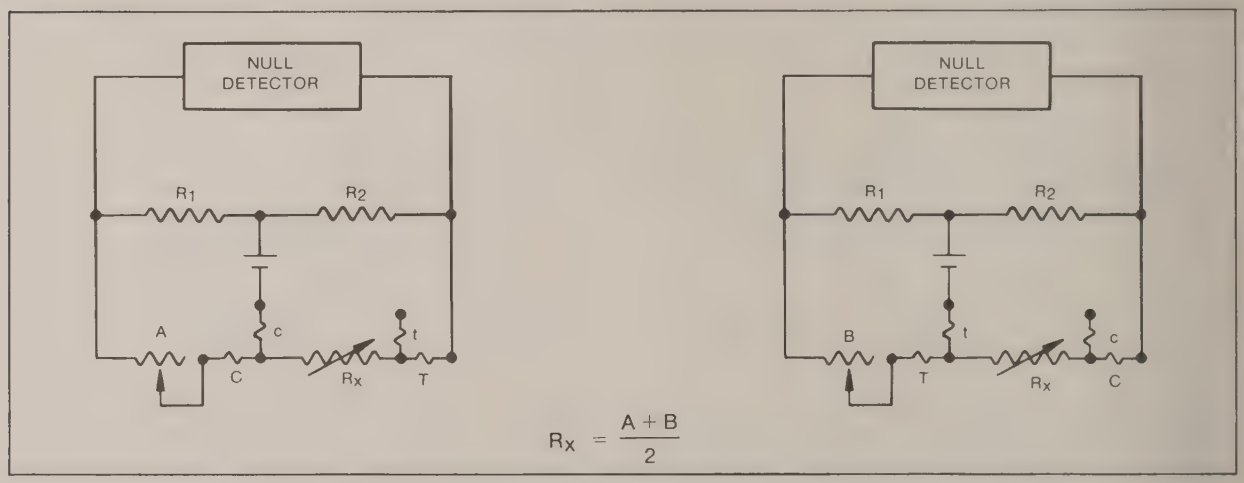

Figure 18. 162 Thermometer Circuit Using a Three-Terminal Wheatstone Bridge.

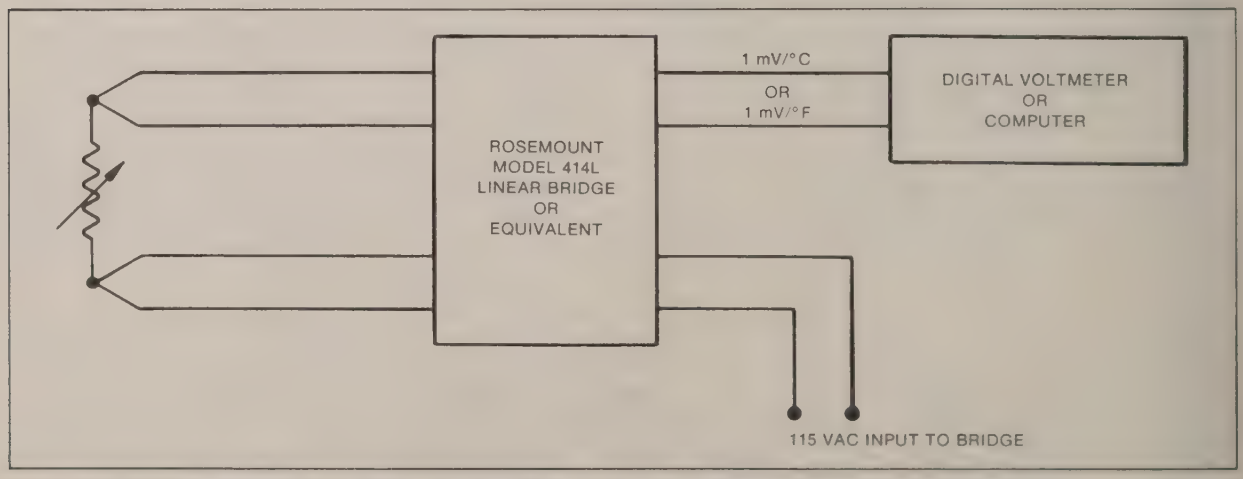

Figure 19. 162 Thermometer Schematic for Digital Temperature Indication.

SECTION IV
OPERATION

GENERAL

Before proceeding with the operation of the Series 162 Temperature Standards, review the operating instructions for the resistance bridge or readout instrument to be used. In addition, prepare the calibration bath according to the manufacturer's instructions.

The best possible measurements can be obtained from a standard thermometer by observing the precautions and techniques outlined in the following paragraphs.

NORMAL MEASURING PROCEDURE

The correct method for making a resistance measurement depends on the particular measurement or readout instrument used. On Mueller bridges, it typically is sufficient to make two balances with normal and reverse current (see Figure 15). Other four-terminal bridges have a reverse key which can be used in combination with the last dial on the bridge to give a single best reading that produces the minimum galvanometer deflection with normal and reverse current. For more precise results, this technique essentially doubles the galvanometer deflection so that the galvanometer scale can be used to interpolate an additional decimal place on the resistance measurement.

A two- or three-terminal bridge measurement assumes equal leadwire resistances during measurement. Although it is not necessary to make a separate leadwire resistance measurement with a three-terminal bridge, normal and reverse current measurements are recommended.

It *is* necessary to make a separate leadwire resistance measurement with a two-terminal bridge (see Figure 17 for recommended connections). This method is preferred over reading C to T as the "element plus leadwires" measurement, and C to c as the "leadwires only" measurement.

CALIBRATION OF OTHER INSTRUMENTS

The number of temperature measurements required to calibrate another instrument depends upon the temperature stability of the calibration bath and the accuracy desired. For best results, make temperature measurements before and after taking readings on the unknown. The two readings (or four when using a Mueller bridge) then should be averaged. Experience may indicate that the calibration bath is stable enough to require only one temperature standard measurement for one or more measurements of the unknown.

Since the ice point resistance for Models 162CE and 162D is 25.55 ohms, the change in resistance is very nearly 0.1 ohm/°C (.0001 ohm/mK). This makes it convenient for the user to estimate temperature changes when monitoring on a resistance bridge.

MEASURING CURRENT

A platinum resistance thermometer requires electrical current to make the resistance measurement. The effect of the current is to self-heat the sensing element so that its temperature is slightly higher than the temperature to be measured. The Series 162 Temperature Standards have low self-heating effects, consequently self-heating usually is not a significant source of error. Self-heating also is normally lower when the thermometer is in contact with a liquid or a metal block than when it is immersed in a gas. Table 2 lists typical self-heating effects and nominal measuring currents.

TABLE 2

COMPARATIVE SELF-HEATING CHARACTERISTICS IN A STIRRED ICE BATH

Model	Self-Heating mW/°C	Nominal Current mA	Error at Nominal Current mK
162CE	85	1.0	0.3
162D	85	1.0	0.3
162K	11	10	2.0
162N	28	2 to 6*	23 to 75

*Nominal currents for 1 mV/°C or 1 mV/°F output using Rosemount 414L Linear Bridge.

The Rosemount and NBS calibration tables for Models 162CE and 162D are correct at 1 mA measuring current, i.e., if 1 mA is used, self-heating corrections need not be made. Likewise, if Model 162N is calibrated and trimmed with a 414L Linear Bridge in a calibration bath, the self-heating is compensated and no corrections need be made.

For extremely accurate measurements where errors due to self-heating are unknown or significant, determine the "zero current" resistance as follows:

Make a resistance measurement at two different currents. Plot the i^2R power (or i^2) against R as shown in Figure 20, and extrapolate to zero power (or zero current). Equation 1 below provides the same result. Calibration tables for the 162K are prepared by this method, and the technique can be used for evaluating the self-heating effects of any resistance thermometer.

$$R_O = R_1 - \frac{i_1^2 (R_2 - R_1)}{i_2^2 - i_1^2} \qquad (1)$$

where R_O = Zero current resistance
R_1 = Resistance measured at current i_1
R_2 = Resistance measured at current i_2

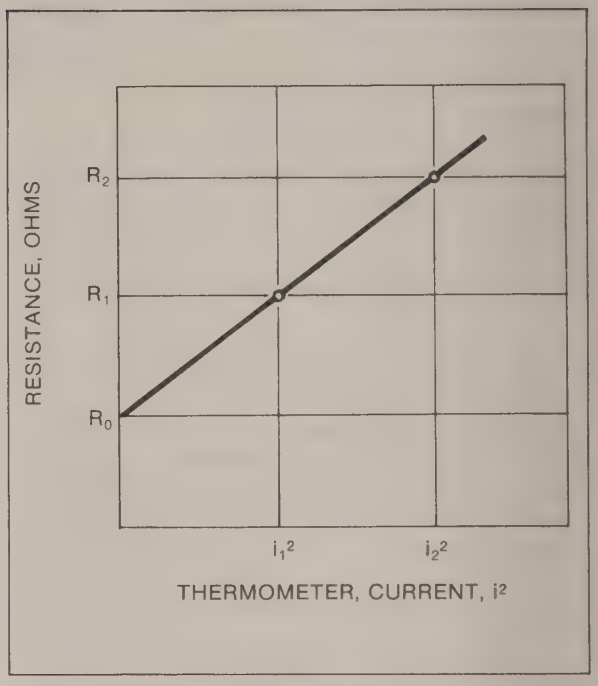

Figure 20.
Determination of Zero Current Resistance.

IMMERSION REQUIREMENTS

A 162 Temperature Standard not fully immersed in the fluid where temperature is being measured will exhibit an error due to heat lost or gained by the sensing element through the thermometer stem. Thus, it is essential that each temperature standard has a low thermal cross section to minimize stem conduction. Models 162CE and 162N are designed primarily for use in liquids. Typically, an immersion depth of 4 to 4-1/2 inches (10 to 12 cm) produces conduction errors no greater than 1 mK.

When determining immersion depths, the following procedure is recommended:

With the bath temperature uniform and constant while measurements are being made, immerse the thermometer as deep as possible and record the resistance. Withdraw the thermometer 2 to 4 cm at a time, allow it to stabilize, and record the new resistance until the change between readings is quite noticeable. Figure 21 shows a convenient method of plotting the results.

In the Model 162K, heat losses are further affected by radiation losses from the sensing element to the housing. The matte finish on the quartz sheath minimizes losses in the wall of the sheath by preventing internal reflections. Quartz leadwire spacers provide multiple radiation shields along the leadwires. Small diameter platinum leadwires in series with the larger leadwires adjacent to the sensing element supply additional thermal resistance to minimize conduction losses. If the 162K is used in an oil or ice bath, a 6-inch (15.24 cm) immersion depth is sufficient. Full immersion is recommended if the 162K is used in a furnace or freezing point cell.

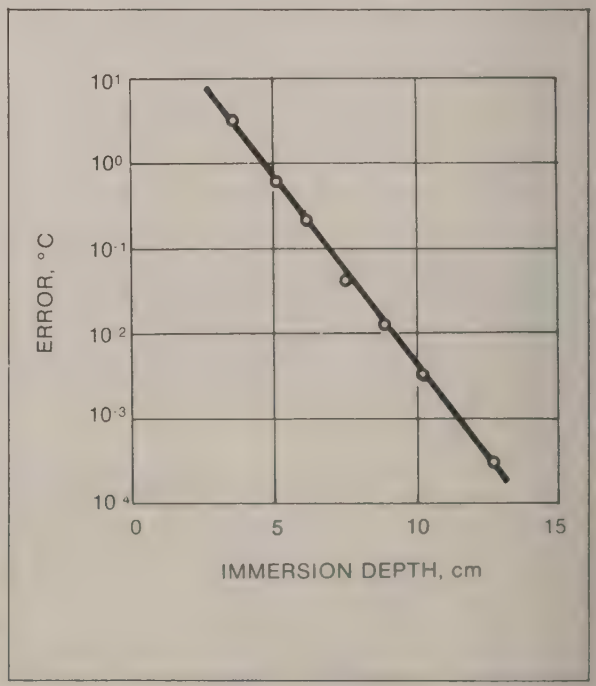

Figure 21. Stem Conduction Effects in a Stirred Ice Bath - Model 162K.

THERMAL EMF

Thermal emf can occur any time an electrical circuit consisting of dissimilar metals passes through a temperature gradient. Even a pure platinum wire exhibits thermal emf due to stresses at the grain boundaries. The Series 162 Temperature Standards exhibit minimal thermal emf because the platinum leadwires are annealed along their full length, and the joints between the platinum and copper leadwires are carefully heat sinked.

Connections to extension leadwires and readout devices also are a source of thermal emf. To minimize this source of error, cover or insulate exposed bridge and galvanometer terminals.

The presence of thermal emf can be detected on a bridge using DC excitation by obtaining a bridge balance, reversing the direction of current flow through the sensing element, and obtaining a second balance. Correct the resistance for thermal emf by averaging the two readings. AC excitation eliminates the effect of thermal emf; however, inductive and capacitive effects then must be considered.

INSULATION RESISTANCE EFFECTS

The insulation in a resistance thermometer acts like a resistor in parallel with the sensing element. In the 162CE, 162D, and 162K Temperature Standards, the insulation should not cause more than a 1 ppm (or 1 mK) error in the operating range. This error is approximated in Equation 2.

$$\Delta T = -\frac{R_t^2}{R_s(dR/dT)} \text{ if } R_s >> R_t \qquad (2)$$

where

R_t = Thermometer resistance at temperature T, ohms
R_s = Insulation resistance, ohms
dR/dT = Slope, ohms per degree

The value of R_s is approximated by measuring the insulation resistance between the sensing element and the thermometer housing. Nominally, R_s should measure greater than one million times R_t.

High temperatures can have a significant effect on resistance thermometers since the insulation resistance decreases rapidly as the temperature increases. Because of this effect, the 162 Series includes the low 0.22-ohm 162K, whose insulation resistance at 1100°C is approximately 1 Megohm. The 162N has a greater error due to the comparatively larger 100-ohm sensing element resistance; however, the error should not exceed 0.05°C at 400°C.

Another insulation resistance factor to consider is the so-called "wet kick" of a galvanometer caused by polarization of water molecules in or on the insulating surfaces of the thermometer. When the current is reversed at a balanced condition, the galvanometer gives a "kick" with a decay time from a few seconds to over a minute before returning to its former position.

HIGH TEMPERATURE APPLICATIONS

As temperature increases, the equilibrium concentration of point defects present in the platinum wire of a standard thermometer also increases. If the sensing element is cooled quickly from temperatures above 600°C, some of these defects are frozen into the crystal structure, causing a slight increase in resistance. For example, a Model 162K cooled from 1100°C to room temperature in less than a minute will exhibit a resistance increase equivalent to 0.06°C at 0°C. This effect is reversible and the original resistance can be recovered by subsequent annealing. The same Model 162K cooled from 1100°C to room temperature in 30 minutes or longer will show complete recovery. Thus, the best procedure is to avoid high cooling rates if the thermometer is used above 600°C.

TREATMENT OF ERRORS

Errors are classified as either systematic or random. Systematic errors are those whose direction and magnitude can be predicted or determined. As such, they may be subtracted or added to the final result. Random errors have magnitudes and directions which cannot be precisely predicted. A certain amount of randomness typically is associated with systematic errors--about three times the standard deviation of a group of measurements. Consequently, a systematic error which is not corrected becomes a random error.

After the individual errors have been estimated and the systematic errors added algebraically to the measured temperature, the random error can be calculated by the square root of the sum of the squares for the individual errors (RSS). This calculation is shown in Equation 3.

$$\Delta T_{RSS} = \left[\sum_{i=1}^{n} (\Delta T_i)^2\right]^{1/2} \qquad (3)$$

For calibration errors, a detailed analysis of calibration uncertainty usually can be made at the calibration points. Any of a number of methods is effective in calculating the uncertainty between calibration points. One such method is the following analysis of a comparison calibration of a standard thermometer at −183°C, 0°C, +100°C and +260°C.

First, the significant errors are tabulated in mK at the calibration points (see Table 3). A nominal R versus T table is then calculated. Next, the calibration data for one point is offset by an amount equal to the RSS error in Table 3. A new R versus T table is generated, and the difference between the new curve and the nominal curve is calculated. This is done for each of the calibration points and summarized in Table 4. (The actual computation for this table involves more calculated points; those included in the table illustrate the method.)

A graphical summary of uncertainty (error) versus temperature is shown in Figure 22. Note that the smallest errors occur at the calibration points, and that the errors increase between calibration points.

TABLE 3
SUMMARY OF ERRORS AT CALIBRATION POINTS

Error	Temperature			
	−183°C mK	0°C mK	+100°C mK	+260°C mK
Uncertainty in Primary Standard	3.0	0.5	1.5	1.9
Uncompensated Shift in Primary Standard	2.0	0.1	0.3	0.8
Bridge Error	0.006	0.25	0.35	0.5
Bath Non-Uniformity	2.0	0.2	1.0	3.0
Stability of Unknown	0.25	1.0	1.4	2.0
RSS Error, mK (Equation 3)	4.13	1.17	2.33	4.18

TABLE 4
SUMMARY OF ERRORS OVER OPERATING RANGE

Temperature °C	T — T (Nominal)				RSS Error mK
	−183°C mK	0°C mK	+100°C mK	+260°C mK	
−200	5.8	−1.0	1.1	0	6.0
−183	4.1	0	0	0	4.1
−150	2.1	1.2	−1.3	0	2.7
−100	0.5	1.9	−1.7	0	2.6
−50	0	1.7	−1.1	0	2.0
0	0	1.2	0	0	1.2
+50	0	0.5	1.5	−0.2	1.6
+100	0	0	2.3	0	2.3
+150	0	−0.3	2.4	0.7	2.6
+200	0	−0.3	1.8	2.0	2.7
+260	0	0	0	3.8	3.8
+300	0	0.4	−1.9	6.1	6.4
+350	0	1.1	−5.0	9.1	10.4
+400	0	2.1	−9.0	12.6	15.6
+450	0	3.4	−13.9	16.9	22.1
+500	0	5.0	−19.9	21.8	29.9
+550	0	6.9	−26.9	27 5	39 0
+600	0	9.2	−35.0	33.9	49 6
+650	0	11.8	−44.3	41.1	61.5

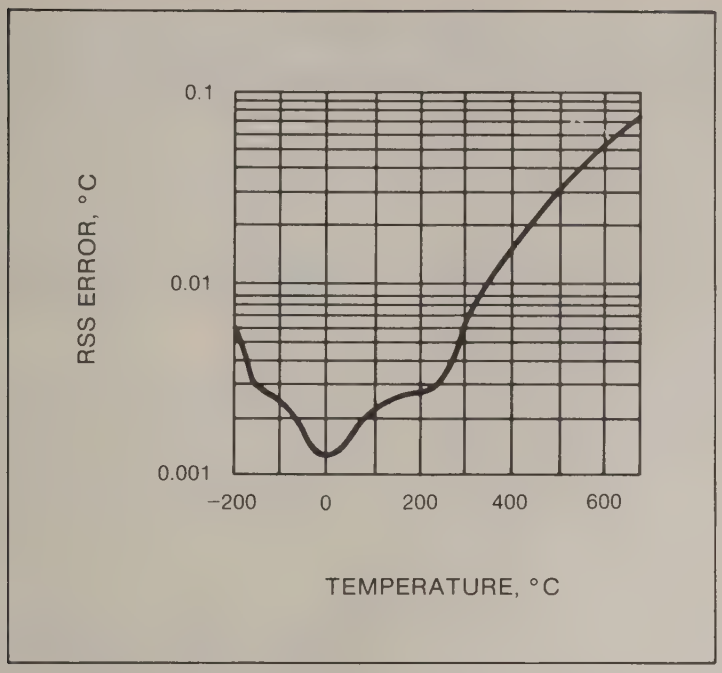

Figure 22. Graphical Summary of Error Analysis.

SECTION V
CALIBRATION AND MAINTENANCE

GENERAL

The Series 162 Platinum Resistance Temperature Standards must be calibrated to make accurate temperature measurements. Calibration can be accomplished by Rosemount or any other recognized standards laboratory equipped to perform temperature calibration.

RESISTANCE VERSUS TEMPERATURE TABLES

Rosemount supplies tables of resistance R_t in absolute ohms versus temperature according to a number of different schedules (see Table 5). The increment size is sufficient to allow linear interpolation to a precision of 1 mK or 0.001°C.

TABLE 5
CALIBRATION SCHEDULES

Calibration Schedules	Applicable Models	Description
	Rosemount Inc.	
162-97-1	162CE, D, N	−183°C to 500°C in 1°C increments[1]
162-97-2	162CE, D, N	−297°F to 930°F in 1°F increments[1]
162-97-3	162CE, D, N	−200°C to 500°C in 1°C increments[1]
162-97-4	162CE, D, N	−320°F to 930°F in 1°F increments[1]
162-97-5	162D only	13 K to 90 K in 0.1 K increments
162-97-6	162D only	13 K to 90 K in 0.1 K increments 90 K to 550 K in 1 K increments
162-97-7	162K only	0°C to 1100°C in 1°C increments
162-97-8	162CE, D, N	0°C to 500°C in 1°C increments[1]
162-97-9	162CE, D, N	32°F to 930°F in 1°F increments[1]
162-97-10	All models	0°C measurement only
162-97-11	162CE	−183°C to 650°C in 1°C increments
162-97-12	162CE	−297°F to 1200°F in 1°F increments
162-97-13	162CE	−200°C to 650°C in 1°C increments
162-97-14	162CE	−320°F to 1200°F in 1°F increments
162-97-15	162CE	0°C to 650°C in 1°C increments
162-97-16	162CE	32°F to 1200°F in 1°F increments
A-C	162N	−180°C to 500°C in 10°C increments
A-F	162N	−290°F to 930°F in 20°F increments
	National Bureau of Standards	
7.3B	162CE	−50°C to 500°C or 630°C in 1°C increments
7.3C	162CE	−183°C to 500°C or 630°C in 1°C increments
7.3E	162D	13 K to 90 K in 0.1 K increments 90 K to 300 K in 1 K increments
7.3F	162D	−183°C to 300°C in 1°C increments

[1]Calibration tables are limited to 300°C or 600°F for the 162D, and 400°C or 800°F for the 162N because of temperature limitations.

Another method of presenting data is a table of resistance ratio (R_t/R_0) versus temperature. The resistance ratio tends to be more stable over time than absolute resistance. When using this type of table, it is necessary to use the current ice point resistance R_0 along with the measured R_t in order to determine temperature. Tables for Model 162K are prepared in this manner. Resistance ratio tables can be prepared by Rosemount for most of the calibration schedules listed in Table 5 at no additional charge if specified at the time a temperature standard is calibrated.

A significant advantage of using resistance ratio tables is that temperatures can be determined independent of the value of the absolute ohm if both R_t and R_0 are measured on the same resistance bridge. Thus, even if the customer's bridge calibration differs slightly from the bridge used to calibrate the temperature standard, accurate temperature measurements can be made using resistance ratios.

If several calibrations of an unknown thermometer will be performed at only a few temperatures, interpolation time can be minimized with a computer-prepared table of resistance versus temperature where resistance is expressed in the smallest increments readable on the bridge.

If a more sophisticated technique for production quantity calibration is required, a digital computer can be programmed to calculate temperature directly from a resistance input, using the equations and constants supplied with the calibration tables.

CALIBRATION INTERVAL

Two factors affect the frequency with which a temperature standard should be calibrated: the level of accuracy required, and the conditions of use.

To determine when a temperature standard should be recalibrated, periodically measure and record the resistance at the freezing point or triple point of water. When the change in resistance exceeds a predetermined amount, the thermometer should be recalibrated.

An example of the preceding method is a working temperature standard used for routine calibrations and allowed to change by the equivalent of 0.005°C (0.0005 ohms for Model 162CE) before being recalibrated. The ice point resistance is recorded weekly and is found to increase slowly with time, approximately 0.010°C per year. The recalibration interval for this instrument is, therefore, six months. If a 0.03°C shift was allowed, the recalibration interval would be three years.

There are significant advantages in monitoring the resistance of a temperature standard at a fixed point. The reliability in the overall resistance measuring accuracy and repeatability over a long time period can be determined. If the temperature standard is calibrated in terms of resistance ratio R_t/R_0 described previously, the current value of R_0 can be used. An additional advantage is that the condition of the temperature standard can be checked. Normally, the value of R_0 will change in a slow, continuous manner, increasing with time. Any sudden change could indicate that the instrument has been subjected to rough handling, may have become contaminated, or that there are problems with the measuring equipment, or measuring technique. When these problems occur, it is convenient to have a second temperature standard to use for further tests.

CALIBRATION OF PRIMARY STANDARDS

Models 162CE, 162D, and 162K are considered primary temperature standards. As indicated in the "Introduction" section of this manual, Rosemount supplies calibration results traceable to the NBS for all 162 Temperature Standards. The calibration schedules available from Rosemount and the NBS are summarized in Table 5. Other independent laboratories equipped to calibrate temperature standards also may be used to calibrate primary standards.

CALIBRATION OF SECONDARY STANDARDS

The ice point reading of Model 162N, a secondary standard, should be periodically checked to determine when recalibration is necessary. The 162N typically is matched with the Rosemount Model 414L Linear Bridge and a digital voltmeter. (Complete operating procedures for the Model 414L are included in Rosemount Instruction Manual 4001). Rosemount can recalibrate the temperature standard-linear bridge combination, or the customer can calibrate the bridge using the procedures outlined on page 18.

The accuracy provided by calibration schedules A-C or A-F (see Table 5) is sufficient for the 162N-414L combination. During bridge calibration, a precision resistance decade box (0.01 ohm resolution, such as General Radio Type 1432-T) is substituted for the 162N Temperature Standard. Four leadwires are used to connect the bridge to the decade box.

1. Determine the resistance value of the thermometer at 0°C or 0°F, depending on the output range for which the bridge was designed. (Refer to the calibrated resistance versus temperature curve described previously.) Set this resistance value on the decade box.
2. Allow the bridge a minimum of 15 minutes warm-up time.
3. The voltmeter should read zero millivolts. If it does, proceed to step 5. If the voltmeter reads other than zero, complete step 4.
4. The top of the bridge has three adjustment screws labeled "L", "S", and "Z" (zero). Do not adjust the "S" or "L" screws at this time. (NOTE: Some models of the bridge have the "L" screw at the bottom.) Adjust the "Z" screw until the voltmeter reads zero millivolts. No further adjustments to the "Z" screw are necessary.
5. Determine the resistance value of the thermometer at the temperature which corresponds to a full-scale reading. Set this resistance value on the decade box.
6. The voltmeter should read the full-scale temperature value. If it does, proceed to step 8. If the voltmeter reads other than the full-scale temperature value, complete step 7.
7. Adjust the "S" screw until the voltmeter reads the full-scale temperature value.
8. Determine the resistance value of the thermometer at the temperature which corresponds to a mid-scale reading. Set this resistance value on the decade box.
9. The voltmeter should read the mid-scale temperature value. If it does, repeat steps 5 and 6 as a recheck. If the voltmeter reads other than the mid-scale temperature value, complete step 10.
10. The mid-scale reading is determined by adjusting both the "L" and "S" screws. Because of the interaction between them, both adjustments must be trimmed. The error should be overcorrected by a factor of 8 with the "S" screw, and then readjusted with the "L" screw.

Example -

Desired mid-scale reading:	200 mV
Actual millivolt output reading:	200.3 mV
Error:	+0.3 mV
Correction factor:	$8 \times 0.3 = 2.4$ mV
Adjust "S" screw to obtain:	$200 - 2.4 = 197.6$ mV
Readjust "L" screw to obtain:	200 mV

The accuracy of the decade box limits the system accuracy. However, system accuracy can be improved by an in-bath calibration at the end points after the bridge has been trimmed to the resistance versus temperature data. With the 162N in a calibration bath at a known temperature at or near the bridge zero, adjust the "Z" screw. A similar modification can be made on the "S" screw near the other end of the bridge range. Accuracy can be improved further by deriving an error curve over the operating range of the bridge. To obtain this, substitute resistances corresponding to known temperatures and plot the resultant differences versus temperature.

LEADWIRE FAILURES

Leadwires may fail after several years of service due to repeated flexing and handling. Open or shorted leadwires can cause erroneous readings. Use an ohmmeter to check leadwire continuity (see Figures 13 and 14). The insulation resistance from each leadwire to the outside sheath should exceed 100 Megohms. If a problem exists, remove the housing of the temperature standard to expose the leadwire connections.

The 162CE and 162K housings are threaded onto the sensor body. Remove the 162N housing by unscrewing the knurled retainer. Ensure that the exposed leadwires are not touching each other or the inside of the housing. Check the sensing element leadwire continuity from the hermetically-sealed pins inside the housing.

Rosemount replaces faulty leadwires on all Series 162 Temperature Standards. Failures which occur within the sensing element itself are generally nonrepairable; however, the temperature standard should be returned to Rosemount for evaluation since some failures can be repaired (see "Return of Hardware" section for procedures).

INSULATION RESISTANCE

On the primary temperature standards--Models 162CE, 162D, and 162K--the insulation resistance in parallel with the sensing element should be sufficiently high so that the measured thermometer resistance is not affected by more than 1 ppm or 1 mK. The insulation resistance from the sensing element to the outside sheath is representative of the actual shunting resistance. Generally, this resistance should be greater than one million times the sensing element resistance at any temperature within the thermometer's operating range.

Model 162N, a secondary standard, may not always achieve the high insulation resistance required of the primary standards because it has high sensing element resistance and is constructed differently. The main criterion for high temperature operation is that the insulation resistance remains constant with time.

Low insulation resistance may be indicative of moisture within the temperature standard or on the hermetically-sealed pins inside the housing. Eliminate external moisture by removing the housing, carefully cleaning the pins with alcohol or other suitable solvent, and blowing them dry. Internal moisture may be indicative of a leak in the temperature standard. If a leak is present, return the thermometer to Rosemount for evaluation.

STABILITY

Typically, the R_0 of a temperature standard increases with time at a nearly linear rate. In most cases this is caused by handling, which introduces small strains into the annealed platinum sensing element wire. Part of the resistance increase can be recovered by annealing the sensing element portion of the temperature standard in a small laboratory furnace for 2 to 4 hours at temperatures of 300°C (162D), 400°C (162N), or 650°C (162CE). The 162K should not require reannealing since it is normally used above 650°C.

Another cause of stability shifts is contamination of the sensing element. A slow, irreversible increase in R_0 with time is normal, and may be disregarded. However, a leak in the sheath or exposure to temperatures above the operating range can cause contamination, resulting in a higher drift rate. A contaminated standard thermometer still can be used, but should be assigned wider error limits or recalibrated more frequently.

SECTION VI
RETURN OF HARDWARE

RECALIBRATION

Prior to returning any 162 Temperature Standard to Rosemount or the NBS for recalibration, measure the ice point or triple point resistance (R_0). After receiving the recalibrated temperature standard, again measure the R_0 and compare the results with the R_0 prior to recalibration. This will help detect possible mishandling in transit.

REPAIR

Platinum resistance temperature standards generally are nonrepairable in the field. Contact Rosemount for corrective action for any damages or problems not discussed in this manual.

RETURN PROCEDURES

Exercise extreme care when shipping a 162 Temperature Standard. Place the thermometer in its storage case (see "Specifications" section), and then in a wooden crate which has approximately 3 to 4 inches (7.6 to 10.2 cm) of soft insulation on all sides to cushion the instrument against mechanical shocks. The cover for the crate should be attached with screws or clamps; a nailed-on cover is not suitable. Air shipment is recommended to ensure more careful handling in transit.

162 Temperature Standards returned for recalibration or repair, whether in or out of warranty, should be shipped prepaid to:

Rosemount Inc.
AGI Division
12001 West 78th Street
Eden Prairie, MN 55343

The shipping crate should be marked:

Return for Recalibration or Repair
162 (Model CE, D, K, or N) Platinum
Resistance Temperature Standard

If the temperature standard is being returned for repair, it should be accompanied by a letter which contains the following information:

1. Application and length of time in service of the thermometer.
2. Description of the faulty operation, and circumstances of the failure.
3. Name and telephone number of the person to contact if there are questions about the returned thermometer.
4. Request for warranty or non-warranty service, as applicable. For non-warranty repair, enclose a purchase order for the service requested.
5. Complete shipping instructions for return of the thermometer to the customer.

Adherence to these procedures will expedite handling of any temperature standard returned for repair, and will prevent unnecessary additional charges for inspection and testing to determine the problem with the instrument.

SECTION VII
BIBLIOGRAPHY

The references listed below provide additional information on the history, theory, and use of standard platinum resistance thermometers and temperature calibration.

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